

Comment on “Quantum Solution to the Arrow-of-Time Dilemma”

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In this paper we criticize the attempt of Maccone [Phys. Rev. Lett. **103**, 080401 (2009)] to solve the problem of the arrow of time.

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Recently, Maccone [1] has shown that all phenomena which leave a trail behind (and hence can be studied by physics) are those the entropy of which increases. From that he concluded that the second law of thermodynamics is reduced to a mere tautology, suggesting that it solves the problem of the arrow of time in physics. Namely, according to [1], one observes that entropy always increases with time (or remains constant) simply because processes in which entropy decreases with time, if they exist, cannot be detected.

In this Comment we criticize the conclusion above. To be clear, we agree with the result of [1] that an observable physical phenomenon must leave a trail and that leaving a trail necessarily increases entropy. Nevertheless, we argue that this fact does not help much to understand the origin of the arrow of time. More precisely, we discuss 3 different problems (where two of them, denoted by 2a) and 2b), are not completely independent) with the arrow of time that the results of [1] do not solve.

1) *The problem of macroscopic entropy-decreasing processes.*—Let us explain this problem through a simple example from everyday life. The forces of nature (earthquakes, hurricanes, etc.) can easily destroy a house, but they cannot easily build one. This is so because a destroyed house has a larger entropy than an undestroyed one. (This refers to macroscopic coarse-grained entropy, which should be distinguished from thermodynamic entropy which is coarse-grained on a finer level.) If processes in which entropy decreases exist, then one should expect the existence of processes in which houses are built spontaneously. Indeed, such a process can leave a trail in another medium (say on the film tape that records it) in which the entropy increases, so such an entropy-decreasing process should be observable. Yet, we do not see such processes in nature and the results of [1] cannot explain why.

2a) *The trace-from-the-future problem.*—According to [1], an entropy-decreasing transformation cannot leave any trace. However if, *a priori*, both directions of time have completely equal roles in physics, then this cannot be true. This is because *decreasing* is the same as *increasing* in the opposite time direction. Hence, if an

entropy-increasing transformation leaves a trace from the past, then an entropy-decreasing transformation leaves a trace from the future. Yet, in nature we do not see traces from the future and the results of [1] do not explain why. Of course, the fact that we do not see traces from the future can be explained from the assumption that (for some unknown reason) we live in a universe in which entropy *does* increase with time (this is, indeed, the standard explanation [2]), but the idea of [1] is to avoid that assumption entirely.

2b) *The existential time-arrow problem.*—The problem 2a) can be cheaply avoided by a “common sense” argument that traces from the future cannot exist because the future does not yet exist. However, such an argument presumes that the future is not equally real as the past, i.e., that a preferred direction of time exists. Therefore, we refer to the paradigm according to which the future does not yet exist as the existential time arrow. In this way, [1] cannot completely explain the origin of the arrow of time, but at best can explain the thermodynamic time arrow from the assumption of the existential time arrow. (This should be contrasted with the standard view [2] according to which the existential time arrow is only an illusion emerging from the assumption that entropy increases with time.)

To conclude, the results of [1] do not help much to solve the difficult problem of the origin of the arrow of time.

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[1] L. Maccone, Phys. Rev. Lett. **103**, 080401 (2009) [arXiv:0802.0438].

[2] For an extensive list of standard literature on the origin of the arrow of time see [1].